Combining ability and heterosis in single crosses derived from some local maize (*Zea mays* L.) inbred lines

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ABSTRACT

This study was conducted to assess the grain yield, combining ability and heterosis of some local maize (*Zea mays* L.) inbred lines and then hybrids. Experiments were carried out during autumn in 2008 at Gezira Research Station (GRS) and Matuq Research Station (MRS) of the Agricultural Research Corporation (ARC), Sudan, in a randomized complete block design with three replications. Combining ability was studied among 8 (4 white and 4 yellow) local inbred lines of maize and their 28 F_1 crosses. Most of the parents were late flowering except L-11 and L-12. Results of mean grain yield performance showed that crosses L-11×L-7 and L-14×L-7 were the best at GRS with means of 6229 and 6147 kg ha, respectively; while at MRS, crosses L-14× L-3 and L-7× L-1 were the best with mean grain yields of 3929 and 3860 kg/ha, respectively. Combined analysis of variance across sites identified L-3×L-7 and L-14×L-7 as the top grain yielders coupled with earliness and short plant height. Combining ability analysis revealed that non-additive genetic effects were more important for the measured traits. Lines L-7 and L-1 showed the best GCA effects for grain yield and 100 kernels weight in GRS, while L-11 and L-13 in MRS. Lines L-9, L-12 and L-11 were good general combiners for earliness. Maximum heterosis for grain yield (79.2%) was obtained in the cross L-14xL-7 at GRS, while L-14xL-3 at MRS (218.1%). At both locations, crosses L-14xL-7, L-14xL-3, L-1xL-9, L-14xL-9 and L-11xL-3 were the best specific combiners (SCA) for grain yield that associated with good SCA effects and heterotic pattern. Hence, these hybrids could be recommended for further testing in multi-location trails to confirm the consistency of their grain yield.

INTRODUCTION

Maize (*Zea mays* L.) is one of the oldest food grains in the world. In the Sudan, maize occupies 36960 hectares with production of 70000 tones and average grain yield of 1894 kg ha (AOAD, 2007). Maize breeding programs designed for specific-end uses, improved maize genotypes tolerant to pests/diseases, and development of commercial maize hybrids usually require good knowledge of combining ability of the breeding materials to be used. Evaluation of crosses among inbred lines is an important step towards the development of hybrid maize (Hallauer, 1990). The diallel analysis provides good information on the genetic identity of genotypes especially on dominance-recessive relations and some other genetic interactions (Sujiprihati *et al.*, 2001).

To increase productivity and total production of maize, it is necessary to develop hybrid maize and gradually substitute the open pollinated varieties (OPVs) with the hybrids, depending on farmers' preference and availability of sustainable seed source. One of the long term objectives of maize research programme at the Agricultural Research Corporation (ARC) of the Sudan is to develop new maize hybrids from crosses among locally developed inbred lines and incorporate the advantages of higher yield, adaptability and tolerance to weeds, diseases and insect pests into their genetic backgrounds. Therefore, this study was conducted to fulfill the following objectives: (a) evaluate *per se* performance of 28 maize hybrids and their yield potential; (b) determine the general combining ability (GCA) and specific combining ability (SCA) effects among locally developed inbred lines and their crosses for grain yield and other agronomic traits; and (c) study heterosis, gene action and effects on grain yield and other related traits.

MATERIALS AND METHODS

The source materials were 8 inbred lines developed locally by the Maize Research Program at the ARC. These inbred lines were derived from full diallel crosses of OPVs introduced from CIMMYT-Mexico and landraces in 1997 (Meseka, 2000). Later generations were advanced through half-sibing and pedigree methods (Meseka and Nour, personal communication). The 8 inbred lines were subjected to half diallel mating design following method 2, model 1 of Griffing (1956) to generate 28 F1 hybrids through hand pollination at the Gezira Research Station (GRS) in July 2007. The inbred lines were designated as L-11, L-13, L-14, L-12, L-3, L-7, L-1 and L-9, later grouped according to kernel color. The white color kernels were L-1, L-12, L-13 and L-14, and yellow ones were L-3, L-7, L-9 and L-11.

Two experiments were carried out during the rainy season at Gezira (GRS) and Matuq Research Station (MRS). The trails were arranged in a randomized complete block design with three replications. Each entry was planted on two ridged rows 3 m long, with inter and intra-row spacing of 0.80 m and 0.25 m, respectively, giving a total plot area of 4.8 m^2. The experiments were sown during the first week of July 2008 at both GRS and MRS. Standard cultural and agronomic practices recommended by the ARC were followed at the two locations.

Supplementary irrigation was applied whenever needed to overcome the effects of water stress. At flowering, data were collected on days to 50% tasseling and silking, plant and ear heights (cm). At physiological maturity when the leaves and husks of the plant started to turn yellow and dry, each plot was harvested separately. Data were collected on effective ear length (cm), 100 kernels weight (g) and grain yield later converted into yield per hectare (kg ha^{-1}).

All data were subjected to analysis of variance using the Statistical Analysis System (SAS) computer package (SAS, 1997). Combining ability analysis were carried out by adopting Griffing's (1956) method 2 (parents and crosses), model 1. Analyses of variance for combining ability in half diallel cross for individual locations was conducted.

RESULTS AND DISCUSSION

Variability

The analysis of variance showed highly significant differences among genotypes for all traits in each location (Table 1). The significant differences were observed in mean square at both locations for all traits studied. These results suggested the presence of a wide range of genetic variability in genotypes tested. Such variability is expected since the hybrids used in this study were generated from inbred lines derived from source materials with diverse genetic backgrounds. The amount of variability observed in the material used in this study may lay a foundation for developing hybrids and synthetics that would help in increasing maize production. Hallauer (1990) pointed out that evaluation of crosses among inbred lines is an important step towards the development of hybrid maize.

GCA and SCA variance components

The mean square due to GCA was not significant for most traits except for days to tasseling. The mean square due to SCA were significant ($P<0.01$) for all the traits except effective ear length (Table 1). Sanghi *et al.* (1983) and Sujiprihati *et al.*(2001) stressed on the importance of GCA effects for days to tasseling and silking in eight early maturing composites of maize.

The ratio of GCA to SCA was less than one for all traits measured in this study (Table 1). These ratios indicate that these traits were mainly controlled by non-additive gene action, suggesting that dominance and epistatic interactions seemed to be predominant in the control of these traits. Nanda and Gupta (1967) reported the predominant role of non-additive gene action for grain yield in pearl millet that may be similar in maize since the two species are C4 cereals. As a basic principle in breeding hybrid maize, Sprague and Tatum (1942) emphasized that SCA is more important than GCA among selected inbred lines. However, GCA is relatively more important than SCA
for grain yield traits among unselected maize inbred lines. SCA is an indicator for the predominance of genes having dominance and epistatic effects, while GCA as indicative for predominance of genes having largely additive effects. The importance of non-additive gene action was also emphasized by Alika (1994) and Beck *et al.* (1991). Alika (1994) and Beck *et al.* (1991) who reported that effective ear length was controlled by non-additive gene action.

Performance, combining ability and heterosis

Days to 50% tasseling

At GRS, mean days to 50% tasseling for parents and hybrids ranged from 45 for L-14×L-9 to 56 days for hybrid-351, while at MRS it ranged from 54 for L-11×L-14 to 62 days for L-12×L-3 (Table 2). Favorable GCA values for days to 50% tasseling were scored by parents L-9, L-12 and L-11 with values of -1.48, -1.18 and -0.25, respectively, at GRS, while at MRS parents with good GCA values were L-11, L-9 and L-12 with values of -0.80, -0.50 and -0.20, respectively, (Table 3). These parents transmitted the gene of earliness to their offspring as reflected in our results.

Table 1. Mean squares for combining ability and ratio of GCA to SCA of some agronomic traits measured from 8 maize inbred lines and their 28 crosses evaluated at GRS and MRS during the rainy season of 2008.

S.O.V.	DF	DT	PH	EEL	KWT	GYD
GRS						
Block	2	1.1	2020.5**	12.3**	6.7	1.9*
Genotype	35	19.7**	393.9**	2.9*	37.2**	1.9**
GCA	7	12.7**	318.4	1.6	22.9	0.7
SCA	28	5.0**	84.5**	0.8	9.8**	0.6**
Error	70	0.2	22.0	0.6	1.5	0.1
GCA:SCA		0.3	0.5	0.5	0.3	0.1
MRS						
Block	2	0.4	1265.1**	9.3*	7.1	1.1**
Genotype	35	12.9**	678.5**	5.5**	32.8**	1.4**
GCA	7	5.7*	625.6	2.4	2.9	0.3
SCA	28	4.0**	126.3**	1.7	12.9**	0.5**
Error	70	0.2	32.9	0.9	1.5	0.1
GCA:SCA		0.1	0.6	0.2	0.0	0.1

*, ** Significant at 0.05 and 0.01 levels of probability, respectively.

S.O.V= source of variation, DT= days to 50% tasseling, PH= plant height, EEL= effective ear length, KWT= 100 kernels weight, GYD= grain yield, GCA:SCA= ratio of general to specific combining ability, GRS= Gezira Research Station, MRS= Matuq Research Station.

Estimates of mid-parent heterosis percentage (MPH) for days to 50% tasseling at GRS pointed to favorable direction and ranged from -1.0 for L-7xL-9 to -9.2 for L-3xL-1, while at MRS estimates of MPH ranged from -0.3 for L-13xL-7 to -8.5 % for L-3xL-7 (Table 5). The earliest crosses, L-14×L-9, L-11×L-14, and L-13×L-9 had negative SCA effects and the highest negative heterosis (Tables 2, 4 and 5). These crosses appear to be early in term of maturity that would be suitable for water utilization efficiency and avoidance of late season stem-borer infestation. Identification of early and late maturing genotypes is very important in developing hybrids to suit different agro-ecological zones as well as growers' requirements.

In general, most genotypes at MRS expressed relative late flowering and reached 50% tasseling and silking later than those at GRS. At GRS, most hybrids demonstrated earliness that may be appealing to the vast majority of farmers growing maize in irrigated sector and under limited rainfall conditions. Breeding for earliness is of vital importance in maize hybrids with good agronomic traits to suit the semi-arid tropics such as Sudan. Samanci (1996) emphasized the importance of optimum flowering dates during inbred development as a useful criterion for prediction of hybrid performance. The significant negative GCA observed in this study can be considered as a desirable trait in future breeding programs, since it can contribute to early maturity in the progeny. Crosses L-11×L-14 and L-14×L-9 involved both parents with negative GCA effects.

Plant height

At GRS, mean plant height for the crosses varied from 130, for L-12×L-9, to 185.7 cm, for L-11×L-13, with the general mean of 162 cm (Table 2). Parents L-9, L-12 recorded highly significant negative GCA effects (Table 3). Estimates of MPH ranged from -0.2, for L-7xL-9, to -12.8 %, for L-3xL-7, pointing to the desirable direction (Table 5). However, L-12×L-9 had short plants and early maturing. The cross showed significant negative SCA effects and negatively significantly MPH estimates for plant height. At MRS, mean plant height for the crosses varied from 82, for L-3×L-9, to 141 cm, for L-13×L-7, with the general mean of 116 cm (Table 2). The parental lines with negative and highly significant GCA effects for plant height were L-9, L-3, L-14 and L-1 with values of -13.06, -6.49, -2.43 and -2.16, respectively. Hybrid L-13×L-7 was the tallest hybrid, while L-3 x L-9 was the shortest. Estimates of MPH varied from -1.2 for L-13xL-14 to -19.6% for L-14xL-1 pointing to the desirable direction (Table 5). Crosses L-12×L-9, L-3×L-9 and L-3×L-7 had negative estimates of SCA and heterosis and had the shortest plants among all the genotypes tested at the two locations. Tall maize plants are susceptible to lodging leading to yield losses. As environments in sub-Saharan Africa are often characterized by strong winds, parents with genes for tallness are not desirable for developing maize hybrids.

Table 2. Rank and mean for days to 50% tasseling, plant height (cm) and effective ear length (cm) of 28 F_1 crosses and their parents evaluated at GRS and MRS in autumn season, 2008.

	DT		PH		EEL	
Crosses	GRS	MRS	GRS	MRS	GRS	MRS
L-11	50.0^{IJK}	55.7^{MNO}	163.2^{BCDEFG}	119.0^{BCDEFGHIJ}	14.2^{BCDEF}	12.2^{BCDEF}
L-11× L-13	52.0^{EFG}	59.0^{EFGH}	185.7^{A}	132.7^{ABCDEF}	15.1^{BCDEF}	13.6^{ABCDE}
L-11× L-14	46.3^{PQ}	53.7^{P}	152.3^{FGH}	127.0^{ABCDEFG}	14.8^{BCDEF}	11.8^{DEF}
L-11× L-12	46.7^{P}	55.7^{MNO}	162.3^{CDEFG}	128.3^{ABCDEFG}	14.5^{BCDEF}	13.6^{ABCDE}
L-11× L-3	47.7^{MNOP}	57.7^{HIJK}	176.7^{ABCD}	135.3^{ABC}	14.1^{BCDEF}	13.6^{ABCDE}
L-11× L-7	55.0^{AB}	61.3^{AB}	164.3^{BCDEFG}	133.0^{ABCDE}	16.8^{AB}	13.7^{ABCD}
L-11× L-1	46.7^{P}	56.0^{LMNO}	156.7^{FGH}	125.7^{ABCDEFGH}	15.6^{ABCDEF}	13.1^{ABCDE}
L-11× L-9	49.7^{IJKL}	58.7^{FGHI}	164.0^{BCDEFG}	121.0^{BCDEFGHIJ}	15.7^{ABCDEF}	14.4^{ABCD}
L-13	50.3^{HIJ}	59.0^{EFGH}	158.3^{EFGH}	134.7^{ABCD}	14.8^{BCDEF}	12.9^{ABCDE}
L-13× L-14	51.7^{FGH}	60.3^{ABCDE}	166.3^{BCDEFG}	119.0^{BCDEFGHIJ}	14.7^{BCDEF}	13.1^{ABCDE}
L-13× L-12	47.0^{OP}	56.7^{KLMN}	160.3^{EFG}	127.7^{ABCDEFG}	13.9^{CDEF}	12.9^{ABCDE}
L-13× L-3	53.3^{CDE}	60.7^{ABCD}	166.3^{BCDEFG}	118.7^{BCDEFGHIJ}	14.3^{BCDEF}	12.7^{ABCDEF}
L-13× L-7	54.0^{BCD}	59.3^{DEFG}	179.0^{AB}	140.7^{A}	13.8^{DEF}	14.2^{ABCD}
L-13× L-1	53.3^{CDE}	57.7^{HIJK}	178.3^{ABC}	119.0^{BCDEFGHIJ}	15.5^{ABCDEF}	13.5^{ABCDE}
L-13× L-9	46.7^{P}	55.7^{MNO}	165.7^{BCDEFG}	110.3^{GHIJK}	14.9^{BCDEF}	12.8^{ABCDE}
L-14	48.7^{KLMN}	59.3^{DEFG}	153.7^{FGH}	106.3^{HIJKL}	13.0^{F}	10.3^{EF}
L-14× L-12	48.7^{JKLMN}	58.3^{GHIJ}	159.7^{EFGH}	114.7^{EFGHIJ}	14.8^{BCDEF}	11.9^{CDEF}
L-14× L-3	52.3^{EF}	60.7^{ABCD}	164.0^{BCDEFG}	122.3^{ABCDEFGHI}	14.8^{BCDEF}	15.4^{AB}
L-14× L-7	50.3^{HIJ}	59.0^{EFGH}	163.7^{BCDEFG}	102.0^{JKLM}	17.9^{A}	14.7^{ABCD}
L-14× L-1	47.3^{NOP}	56.7^{KLMN}	168.3^{BCDEF}	90.0^{LMN}	14.8^{BCDEF}	9.5^{F}
L-14× L-9	45.0^{Q}	54.7^{OP}	158.7^{EFGH}	127.0^{ABCDEFG}	14.7^{BCDEF}	15.2^{ABC}
L-12	47.3^{NOP}	56.3^{KLMN}	158.3^{EFGH}	120.3^{BCDEFGHIJ}	14.0^{BCDEF}	11.3^{DEF}
L-12× L-3	49.3^{IJKL}	61.7^{A}	165.3^{BCDEFG}	116.3^{CDEFGHIJ}	14.2^{BCDEF}	11.4^{DEF}
L-12× L-7	52.7^{DEF}	60.7^{ABCD}	154.3^{FGH}	107.3^{HIJKL}	16.6^{ABC}	12.1^{BCDEF}
L-12× L-1	49.3^{IJKL}	57.7^{HIJK}	173.3^{ABCDE}	116.0^{CDEFGHIJ}	15.8^{ABCDE}	11.7^{DEF}
L-12× L-9	46.3^{PQ}	56.0^{LMNO}	130.0^{J}	92.0^{KLMN}	14.7^{BCDEF}	12.4^{ABCDEF}
L-3	54.3^{ABC}	61.0^{ABC}	177.3^{ABC}	91.7^{KLMN}	13.5^{DEF}	11.7^{DEF}
L-3× L-7	48.7^{KLMN}	55.3^{NO}	150.7^{GH}	102.7^{JKLM}	15.1^{BCDEF}	13.3^{ABCDE}
L-3× L-1	47.7^{MNOP}	55.7^{MNO}	163.7^{BCDEFG}	113.0^{FGHIJ}	14.6^{BCDEF}	13.5^{ABCDE}
L-3× L-9	48.3^{LMNO}	58.3^{GHIJ}	143.9^{HI}	82.3^{N}	15.2^{ABCDEF}	13.6^{ABCDE}
L-7	50.7^{GHI}	60.0^{BCDEF}	168.3^{BCDEF}	136.3^{AB}	15.6^{ABCDEF}	14.3^{ABCD}
L-7× L-1	50.7^{GHI}	56.3^{KLMN}	161.0^{DEFG}	115.0^{DEFGHIJ}	15.1^{BCDEF}	15.7^{A}
L-7× L-9	49.0^{JKLM}	57.0^{JKLM}	151.3^{GH}	102.3^{JKLM}	15.6^{ABCDEF}	11.9^{CDEF}

Table 2. (Continued).

L-1	50.7 GHI	57.3 JKLM	161.0 DEFG	117.7 BCDEFGHIJ	15.5 ABCDEF	13.3 ABCDE
L-1× L-9	50.0 IJK	56.7 KLMN	150.7 GH	103.3 IJKLM	16.1 ABCD	12.8 ABCDE
L-9	48.3 LMNO	59.7 CDEFG	135.0 IJ	85.0 MN	13.2 EF	14.0 ABCD
Hybrid-351	55.7 A	56.7 KLMN	178.0 ABC	122.3 ABCDEFGHI	13.9 CDEF	13.6 ABCDE
Mean	49.79	58.08	161.88	115.62	14.9	13.0
C.V.%	2	2	5	9	9	13

GRS= Gezira Research Station, MRS= Matuq Research Station.

Means within the same column followed by the same letter(s) are not significantly different at the probability level of 0.05 according to Duncan's Multiple Range Test (DMRT).

Association of traits is important in predicting the performance and helps in selection. In this study, earliness in maturity was strongly associated with short plant type among the 28 hybrids. Crosses L-12×L-9, L-3×L-9, L-3×L-7, L-7×L-9 and L-1×L-9 were the earliest to flower and had the shortest plants. Significant and positive correlation between plant height and flowering was reported by Elali Elkhalf (2006) who found strong association between late flowering and tall plant type. Estimate of negative GCA effects are preferred for time to flowering and plant height because they are associated with shorter plant type and early maturing genotypes. Relatively short genotypes are more acceptable in areas with high wind velocity and heavy rainstorms that cause lodging and yield losses in taller plants. In our study, hybrids L-3xL-9, L-12xL-9, L-3xL-7 and L-14xL-7 exhibited negative significant heterosis for plant height and days to 50% tasseling. From these results, the parents of these crosses could be utilized in breeding programs to develop early and short hybrids. Our results are in agreement with those of Koirala and Gurung (2002).

Effective ear length

Ear length is an important selection index for grain yield. At GRS, crosses L-14×L-7, L-11×L-7 and L-12×L-7 had the longest ears with means of 18, 16.8 and 16.6 cm, respectively. These crosses showed the highest positive SCA effects and heterosis. At MRS, mean effective ear length for the crosses ranged from 9.5 for L-14×L-1 to 15.7 cm for L-7×L-1(Tables 2, 4, 5). Parents with the highest positive significant GCA effects were L-7 and L-9 with values of 0.72 and 0.41, respectively (Table 3). L-1×L-9 and L-14×L-7 showed the highest positive SCA estimates and positive heterosis (Tables 4 and 5). Hence, L-14×L-7 was the best cross for earliness, short plants and longer ears. Crosses L-14×L-7, L-14×L-3, L-11×L-7 and L-7×L-1 showed the highest grain yield and longer ears. Bellon (1991) reported that kernels obtained from the largest ears, the depth of the kernels on the ears, and larger kernels from the middle part of the ear had the most important selection criteria.

Table 3. Estimates of GCA effects for the measured traits on 8 maize inbred lines, at GRS and MRS, 2008.

Traits	DT		PH		EEL		KWT		GYD	
Parent	GRS	MRS	GRS	MRS	GRS	MRS	GRS	MRS	GRS	MRS
L-11	-0.25*	-0.80**	3.55**	10.21**	0.07	0.12	-0.53*	0.40*	0.05	0.06
L-13	1.22**	0.60**	6.54**	9.84**	-0.25*	0.18	-0.89**	0.76*	-0.23*	-0.05
L-14	-0.75**	0.07	-1.26	-2.43*	-0.20	-0.50*	-2.41**	-0.48*	-0.12*	0.13*
L-12	-1.18**	-0.20*	-3.10**	0.41	-0.18	-0.84**	0.15	-0.49*	0.03	-0.14*
L-3	0.95**	1.07**	3.23**	-6.49**	-0.51**	-0.03	0.94**	0.06	0.19*	-0.05
L-7	1.52**	0.77**	0.80	3.67**	0.76**	0.72**	2.65**	0.18	0.31**	0.23**
L-1	-0.02	-1.00**	2.11*	-2.16*	0.41*	-0.06	0.82*	0.40*	0.24**	0.12
L-9	-1.48**	-0.50**	-11.87**	-13.06**	-0.11	0.41*	-0.72**	-0.83**	-0.47**	-0.31**
S.E.(gi)	0.14	0.14	1.39	1.70	0.24	0.29	0.36	0.37	0.12	0.08

DT= days to 50% tasseling, PH= plant height, EEL= effective ear length, KWT= 100 kernels weight, GYD= Grain yield, GRS= Gezira Research Station, MRS= Matuq Research Station, S.E.(gi)= is standard error for GCA effect of the parent.
*, ** Significant at 0.05 and 0.01 levels of probability, respectively.

100 kernels weight

At GRS, mean 100 kernels weight for crosses varied from 17.3 for L-13×L-9 to 30.4 g for L-11×L-7 with the general mean of 23 g (Table 6). The highest positive and significant GCA effects for this trait were L-7, L-3 and L-1(Table 3). The estimates of mid-parent heterosis ranged from 5.0 for L-14xL-3 to 48.0 for L-13xL-14 pointing to the favorable direction (Table 8). Crosses L-11×L-7, L-3×L-7 and L-7×L-1 produced the highest 100 kernels weight with means of 30.4, 28.9 and 28.8 g, respectively (Table 6). However, these crosses showed positive estimates of SCA effects and heterosis. At MRS, L-1 had the highest 100 kernels weight, while L-14 had the lowest kernel weight. Parents with positive significant GCA effects for 100 kernels weight were L-13, L-11 and L-1 with values of 0.76, 0.40 and 0.40, respectively (Table 3). Mean 100 kernels weight for crosses varied from 13.2 g for L-11×L-14 to 22.5 g for L-11× L-3 with the general mean of 17.2 g (Table 6). Heterosis varied from 0.8 for L-3xL-1 to 93.6 for L-14xL-7 in the favorable direction. L-14×L-7 combined high 100 kernels weight with high grain yield. L-7×L-1 was the best cross for 100 kernels weight as well as earliness, short plants and longer ears, while L-3×L-7 flowered early with short plants and high grain yield. However, the L-11×L-7 had high100 kernels weight, taller plants and late flowering. L-14xL-9 showed favorable heterosis associated with positive significant SCA effects for 100 kernels weight and other agronomic traits as well as negative significant values for days to 50% flowering.

Table 4. SCA effects for the days to 50% tasseling, plant height and effective ear length in 28 maize crosses at GRS and MRS, 2008.

Crosses	DT		PH		EEL	
	GRS	MRS	GRS	MRS	GRS	MRS
L-11× L-13	1.42**	1.27*	14.14**	-2.82	0.38	0.34
L-11× L-14	-2.28**	-3.53**	-11.39**	3.78	0.03	-0.86
L-11× L-12	-1.51**	-1.26**	0.45	2.28	-0.36	1.35*
L-11× L-3	-2.64**	-0.53	8.45*	16.18**	-0.35	0.47
L-11× L-7	4.12**	3.44**	-1.45	3.68	1.00	-0.17
L-11× L-1	-2.68**	-0.13	-10.42*	2.18	0.22	0.04
L-11× L-9	1.79**	2.04**	10.88*	8.41*	0.83	0.87
L-13× L-14	1.59**	1.74**	-0.38	-3.85	0.20	0.41
L-13× L-12	-2.64**	-1.66**	-4.54	1.98	-0.56	0.59
L-13× L-3	1.56**	1.07*	-4.88	-0.12	0.16	-0.42
L-13× L-7	1.66**	0.04	10.22*	11.71*	-1.64*	0.30
L-13× L-1	2.52**	0.14	8.25*	-4.12	0.42	0.42
L-13× L-9	-2.68**	-2.36**	9.56*	-1.89	0.36	-0.79
L-14× L-12	0.99*	0.54	2.59	1.25	0.25	0.23
L-14× L-3	2.52**	1.61**	0.59	15.81**	0.54	2.91**
L-14× L-7	-0.04	0.24	2.69	-14.69*	2.41**	1.45*
L-14× L-1	-1.51**	-0.33	6.05	-20.85**	-0.37	-2.95**
L-14× L-9	-2.38**	-2.83**	10.36*	27.05**	0.07	2.29**
L-12× L-3	-0.04	2.87**	3.76	6.98	-0.01	-0.77
L-12× L-7	2.72**	2.17**	-4.87	-12.19*	1.12*	-0.78
L-12× L-1	0.92*	0.94*	12.89**	2.31	0.68	-0.41
L-12× L-9	-0.61	-1.23*	-16.47**	-10.79*	0.09	-0.21
L-3× L-7	-3.41**	-4.43**	-14.80**	-9.95*	-0.12	-0.43
L-3× L-1	-2.88**	-2.33**	-3.11	6.21	-0.23	0.61
L-3× L-9	-0.74*	-0.16	-8.87*	-13.55*	0.90	0.20
L-7× L-1	-0.44	-1.36**	-3.34	-1.95	-1.03	2.04*
L-7× L-9	-0.64*	-1.19*	0.96	-3.72	-0.02	-2.19*
L-1× L-9	1.89**	0.24	-1.01	3.11	0.87	-0.55
S.E.(Sii)	0.43	0.43	4.26	5.20	0.73	0.89
S.E.(Sij)	0.19	0.19	1.85	2.26	0.32	0.39
S.E.(Sij-sik)	0.63	0.64	6.30	7.70	1.08	1.31

GRS= Gezira Research Station, MRS= Matuq Research Station.
*,** Significant at 0.05 and 0.01 levels of probability, respectively.

Table 5. Average heterosis (%) for days to tasseling, plant height and effective ear length in 28 maize crosses at GRS and MRS, 2008.

Crosses	DT		PH		EEL	
	GRS	MRS	GRS	MRS	GRS	MRS
L-11× L-13	3.7**	2.9**	15.5**	4.6	4.5**	8.4**
L-11× L-14	-6.1**	-6.7**	-3.9	12.7*	9.2**	4.7**
L-11× L-12	-4.1**	-0.6*	1.0	7.2*	2.7**	15.8**
L-11× L-3	-8.6**	-1.1*	3.8	28.5**	2.3**	13.6**
L-11× L-7	9.3**	6.1**	-0.9	4.2	12.5**	3.0**
L-11× L-1	-7.3**	-0.9*	-3.4	6.2	5.4**	2.7**
L-11× L-9	1.0*	1.7**	10.0*	18.6**	15.0**	9.9**
L-13× L-14	4.4**	2.0**	6.6*	-1.2	5.9**	12.9**
L-13× L-12	-3.8**	-1.7**	1.3	0.1	-3.0**	6.6**
L-13× L-3	1.9**	1.1*	-0.9	4.9	1.5*	3.5**
L-13× L-7	6.9**	-0.3	9.6*	3.8	-9.1**	4.2**
L-13× L-1	5.6**	-0.9*	11.7**	-5.7	2.5**	3.2**
L-13× L-9	-5.4**	-6.2**	13.0**	0.5	6.9**	-5.0**
L-14× L-12	1.4**	0.9*	2.4	1.2	9.9**	10.2**
L-14× L-3	1.6**	0.8*	-0.9	23.6**	11.7**	40.3**
L-14× L-7	1.3**	-1.1*	1.7	-15.9**	25.3**	19.2**
L-14× L-1	-4.7**	-2.9**	7.0*	-19.6**	3.9**	-19.4**
L-14× L-9	-7.2**	-8.1**	9.9*	32.8**	12.5**	25.3**
L-12× L-3	-3.0**	5.1**	-1.5	9.7*	3.8**	-1.1
L-12× L-7	7.5**	4.3**	-5.6	-16.4**	12.5**	-5.7**
L-12× L-1	0.7*	1.5**	8.6*	-2.5	7.6**	-5.0**
L-12× L-9	-3.1**	-3.4**	-11.4**	-10.4*	8.6**	-2.4**
L-3× L-7	-7.3**	-8.5**	-12.8**	-9.9*	3.7**	2.0*
L-3× L-1	-9.2**	-5.9**	-3.3	8.0*	0.9	8.4**
L-3× L-9	-5.8**	-3.3**	-7.8*	-6.8	14.2**	5.8**
L-7× L-1	0.0	-4.0**	-2.2	-9.4*	-3.0**	13.6**
L-7× L-9	-1.0*	-4.7**	-0.2	-7.5*	8.2**	-15.8**
L-1× L-9	1.0*	-3.1**	1.8	2.0	12.5**	-6.2**
SE±	0.6	0.6	5s.7	7.0	1.0	1.2

*,** Significant at 0.05 and 0.01 levels of probability, respectively.

GRS= Gezira Research Station, MRS= Matuq Research Station.

Grain yield

At GRS, the mean grain yield for the hybrids ranged from 3610 kg/ha in L-13×L-9 to 6229 kg/ha in L-11×L-7 (Table 6). Parents with positive significant GCA effects were L-7, L-1, and L-3 with values of 0.31, 0.24, and 0.19, respectively (Table 3). The estimates of MPH ranged from 2.0 for L-13xL-3 to 79.2% for L-14xL-7 in the favorable direction (Table 8). Two out of the 28 F_1 hybrids had highly significant mean grain yield than the overall mean. Among the crosses, L-11×L-7, L-14× L-7 and L-12×L-7 gave the highest grain yield with means of 6229, 6147 and 5873 kg/ha, respectively.

These hybrids expressed the highest SCA estimates which were also reflected in highest heterosis values (Table 6).

At MRS, the mean grain yield for parents ranged from 1000 kg/ha for L-3 to 2573 kg/ha for L-11(Table 6). Parents L-11 and L-14 showed the highest negative significant GCA effects for days to flowering as well as highest positive GCA effects for grain yield. Nineteen hybrids recorded relatively higher mean grain yield as compared to the overall mean (2365 kg/ha). Parents L-11 and L-7 were the highest grain yielders (Table 6). Estimates of mid-parent heterosis ranged from 6.9 for L-11xL-9 to 218.1 % for L-14xL-3 in the desirable direction (Table 8). The top-yielding hybrids that combined significant SCA values and positive heterosis were L-14×L-3, L-7×L-1 and L-14×L-7. Crosses L-14xL-9 and L-11xL-3 gave significant negative SCA for days to tasseling and positive for 100 kernels weight and grain yield. L-14xL-7 had significant positive SCA and heterosis for effective ear length and grain yield.

The hybrids that combined yield potential, adaptation and grain quality with considerable high performance for other agronomic traits will make a significant contribution in increasing the yields in the target environments such as vast central clay plains of the Sudan. The mean grain yield was 4652 kg/ha for GRS and 2365 kg/ha for MRS; these differences may be attributed to the different weather and soil conditions. The best five crosses with high grain yield were L-14×L-7, L-14×L-3, L-11×L-7, L-7×L-1 and L-11×L-3. Hybrids L-14×L-7 and L-7×L-1 were consistently the best for grain yield at GRS and MRS. In addition, these crosses had the highest 100 kernels weight, early maturing with short plants. Saleh *et al*. (2002) studying single, double and three-way crosses in tropical maize reported very high MPH estimates for grain yield ranging from 306 to 478%.

Table 6. Means for 100 kernels weight (g) and grain yield (kg/ha) of the maize F_1 crosses and their parents evaluated at GRS and MRS in autumn season, 2008.

Pedigree	KWT		GYD	
	GRS	MRS	GRS	MRS
L-11	20.6 IJKLMN	15.8 GHIJK	4277 DEFGHIJK	2573 CDEFGH
L-11× L-13	21.2 HIJKLM	14.2 IJKLM	4890 BCDEFGH	2051 DEFGHI
L-11× L-14	17.4 LMN	13.2 JKLM	3880 GHIJK	1718 HIJK
L-11× L-12	18.1 KLMN	20.5 ABCDE	4027 FGHIJK	2814 BCDEF
L-11× L-3	26.3 BCDEF	22.5 A	5871 ABC	2628 CDEFGH
L-11× L-7	30.4 A	19.3 ABCDEFGH	6229 A	2610 CDEFGH
L-11× L-1	23.0 DEFGHIJ	21.0 ABCD	4881 BCDEFGH	2963 BCD
L-11× L-9	24.8 BCDEFGH	16.4 EFGHIJK	4083 FGHIJK	1929 FGHI
L-13	17.7 KLMN	15.7 GHIJK	3525 IJK	1745 GHIJ
L-13× L-14	25.7 BCDEF	20.2 ABCDEF	4930 ABCDEFGH	2913 BCDE
L-13× L-12	27.3 ABC	17.9 BCDEFGHI	4847 BCDEFGHI	2742 BCDEF
L-13× L-3	23.1 CDEFGHIJ	19.9 ABCDEFG	4145 FGHIJK	2218 DEFGHI
L-13× L-7	24.4 DEFGHI	21.8 AB	4500 DEFGHIJ	2416 DEFGH
L-13× L-1	24.4 CDEFGHI	18.5 ABCDEFGHI	5624 ABCD	2524 CDEFGH
L-13× L-9	17.3 MN	18.5 ABCDEFGHI	3610 HIJK	2371 DEFGHI
L-14	17.0 N	10.8 M	3260 JK	1471 IJK
L-14× L-12	21.5 GHIJKL	17.2 CDEFGHIJ	4957 ABCDEFGH	2688 CDEFG
L-14× L-3	20.7 HIJKLMN	19.8 ABCDEFG	4997 ABCDEFG	3929 A
L-14× L-7	21.6 GHIJK	21.5 ABC	6147 AB	3385 ABC
L-14× L-1	21.1 HIJKLM	15.2 HIJKL	4740 CDEFGHI	2050 DEFGHI
L-14× L-9	21.5 GHIJKL	21.3 ABC	4550 CDEFGHIJ	2941 BCD
L-12	21.0 HIJKLMN	10.7 M	3865 GHIJK	1484 IJK
L-12× L-3	26.9 ABCD	19.1 ABCDEFGH	5193 ABCDEFG	2021 DEFGHI
L-12× L-7	27.5 ABC	17.2 CDEFGHIJ	5873 ABC	2529 CDEFGH
L-12× L-1	23.3 CDEFGHIJ	19.8 ABCDEFG	5340 ABCDEF	2092 DEFGHI
L-12× L-9	22.7 EFGHIJ	16.9 DEFGHIJ	4220 EFGHIJK	1991 EFGHI
L-3	22.3 FGHIJ	12.3 KLM	4601 CDEFGHI	1000 K
L-3× L-7	28.9 AB	19.0 ABCDEFGH	5547 ABCDE	2755 BCDEF
L-3× L-1	26.9 ABCD	14.2 IJKLM	4620 CDEFGHI	2669 CDEFG
L-3× L-9	19.8 JKLMN	16.2 EFGHIJK	4190 FGHIJK	2553 CDEFGH
L-7	23.0 DEFGHIJ	11.4 LM	3599 HIJK	2070 DEFGHI
L-7× L-1	28.8 AB	20.3 ABCDE	4830 BCDEFGHI	3860 A
L-7× L-9	26.7 ABCDE	14.5 IJKLM	4643 CDEFGHI	1880 FGHIJ
L-1	21.5 GHIJKL	15.9 FGHIJK	4308 DEFGHIJK	1905 FGHIJ
L-1× L-9	25.6 BCDEFG	18.1 BCDEFGHI	5603 ABCD	2455 CDEFGH
L-9	21.1 HIJKLMN	12.3 KLM	3166 K	1037 JK
Hybrid-351	19.3 JKLMN	17.2 CDEFGHIJ	4545 CDEFGHIJ	3588 AB
Mean	22.9	17.2	4652	2365
C.V%.	9	13	15	20

GRS= Gezira Research Station, MRS= Matuq Research Station.

Means within the same column followed by the same letter (s) were not significantly different at the probability level of 0.05 according to Duncan's Multiple Range Test.

Table 7. SCA effects for 100 kernels weight and grain yield in 28 maize crosses at GRS and MRS, 2008.

Crosses	WT		YLD	
	GRS	MRS	GRS	MRS
L-11× L-13	-0.44	-4.19**	0.41	-0.32
L-11× L-14	-2.70*	-3.92**	-0.71*	-0.84*
L-11× L-12	-4.61**	3.41**	-0.71*	0.53*
L-11× L-3	2.77*	4.83**	0.98*	0.25
L-11× L-7	5.23**	1.55	1.21**	-0.04
L-11× L-1	-0.41	3.04*	-0.06	0.42
L-11× L-9	2.98*	-0.35	-0.16	-0.19
L-13× L-14	5.92**	2.76*	0.62*	0.47
L-13× L-12	4.99**	0.41	0.39	0.57*
L-13× L-3	-0.04	1.88*	-0.47	-0.04
L-13× L-7	-0.42	3.69**	-0.23	-0.13
L-13× L-1	1.42	0.15	0.96*	0.10
L-13× L-9	-4.20**	1.36	-0.35	0.37
L-14× L-12	0.71	0.99	0.39	0.33
L-14× L-3	-0.95	3.04*	0.27	1.48**
L-14× L-7	-1.73*	4.61**	1.30**	0.66*
L-14× L-1	-0.38	-1.95*	-0.03	-0.56*
L-14× L-9	1.58	5.40**	0.48	0.75*
L-12× L-3	2.76*	2.38*	0.32	-0.15
L-12× L-7	1.58	0.29	0.88*	0.08
L-12× L-1	-0.80	2.64*	0.42	-0.25
L-12× L-9	0.15	0.98	0.00	0.08
L-3× L-7	2.18*	1.54	0.40	0.21
L-3× L-1	2.02*	-3.45**	-0.46	0.24
L-3× L-9	-3.47**	-0.26	-0.19	0.54*
L-7× L-1	2.24*	2.54*	-0.37	1.15**
L-7× L-9	1.70*	-2.03*	0.15	-0.41
L-1× L-9	2.40*	1.29	1.18**	0.28
S.E.(Sii)	1.10	1.12	0.36	0.25
S.E.(Sij)	0.48	0.49	0.16	0.11
S.E.(Sij-sik)	1.63	1.66	0.53	0.37

GRS= Gezira Research Station, MRS= Matuq Research Station.
*,** Significant at 0.05 and 0.01 levels of probability, respectively.

Table 8. Average heterosis (%) for 100 kernels weight and grain yield in 28 maize crosses at GRS and MRS, 2008.

Crosses	WT		GYD	
	GRS	MRS	GRS	MRS
L-11× L-13	10.8**	-10.0**	25.4**	-5.0**
L-11× L-14	-7.3**	-0.7	3.0**	-15.1**
L-11× L-12	-13.0**	55.0**	-1.1**	38.7**
L-11× L-3	22.3**	59.8**	32.3**	47.1**
L-11× L-7	39.5**	41.8**	58.2**	12.4**
L-11× L-1	9.1**	32.8**	13.7**	32.3**
L-11× L-9	19.1**	16.7**	9.7**	6.9**
L-13× L-14	48.0**	53.1**	45.3**	81.2**
L-13× L-12	41.3**	35.7**	31.2**	69.8**
L-13× L-3	15.4**	42.0**	2.0**	61.6**
L-13× L-7	20.0**	60.9**	26.3**	26.7**
L-13× L-1	24.7**	17.3**	43.6**	38.3**
L-13× L-9	-10.9**	32.0**	7.9**	70.5**
L-14× L-12	13.2**	60.7**	39.1**	81.9**
L-14× L-3	5.0**	71.6**	27.1**	218.1**
L-14× L-7	7.9**	93.6**	79.2**	91.2**
L-14× L-1	9.7**	13.9**	25.3**	21.4**
L-14× L-9	13.0**	84.3**	41.6**	134.6**
L-12× L-3	24.4**	66.5**	22.7**	62.7**
L-12× L-7	24.8**	55.2**	57.4**	42.3**
L-12× L-1	9.5**	48.9**	30.7**	23.4**
L-12× L-9	7.7**	46.6**	20.0**	58.0**
L-3× L-7	27.3**	59.5**	35.3**	79.5**
L-3× L-1	22.7**	0.8	3.7**	83.7**
L-3× L-9	-8.6**	31.1**	7.9**	150.7**
L-7× L-1	29.5**	48.7**	22.2**	94.2**
L-7× L-9	21.2**	22.0**	37.3**	21.0**
L-1× L-9	20.3**	28.1**	49.9**	66.9**
SE±	1.5	1.5	0.5	0.3

GRS= Gezira Research Station, MRS= Matuq Research Station.

*,** Significant at 0.05 and 0.01 levels of probability, respectively.

CONCLUSION

Significant genetic variability was realized in the studied material that will allow for selecting crosses characterized by high grain yield, earliness, and short plants. Five of the best crosses namely; L-11xL-3, L-14xL-3, L-14xL-7, L-14xL-9 and L-1xL-9 were found as good combinations for grain yield along with other traits based on their SCA and heterosis. Accordingly, these hybrids could be recommended for future testing in multi-location trails to further confirm their high yield potential for possible commercial utilization. Hybrid L-14xL-7 combined high grain yield with earliness and short plant statue. The non-additive type of gene action was important in the inheritance of the studied traits. Parents L-7 and L-1 could be considered as desirable lines for grain yield and other agronomic traits that can used in recurrent selection to incorporate its desirable traits.

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القدرة على التوافق وقوة الهجين لهجن فردية مستمدة من سلالات ذرة شامية محلية وذاتية التلقيح (*Zea mays* L.)

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الخلاصة

نفذت هذه الدراسة لتقدير الأداء، القدرة على التوافق وقوة الهجين في سلالات ذرة شامية محلية ذاتية التلقيح. زرعت التجارب في خريف 2008 في محطتي بحوث الجزيرة ومعتوق، هيئة البحوث الزراعية، السودان. استخدم تصميم القطاعات العشوائية الكاملة مع ثلاث مكررات. درست القدرة على التوافق لـ 8 سلالات (4 بيضاء و 4 صفراء) ذاتية التلقيح و28 هجين ناتج منها من خلال التهجين المتبادل والذي طبق في موسم الخريف، 2007. معظم الآباء كانت متأخرة بالإزهار ما عدا L-11 وL-12. أظهرت الهجن L-7×L-11 وL7×L-14 أفضل أداء للغلة الحبية في محطة بحوث الجزيرة مع متوسطات 6229 و6137 كغ/هـ، على التوالي، بينما في محطة بحوث معتوق L-14×L-3 وL-1×L-7 كانت الأفضل مع متوسطات 3929 و 3860 كغ/هـ، على التوالي. أظهرت الهجن L-7×3 -L و L-7×L-14 أفضل أداء للغلة الحبية مترافق مع البكور وقصر النبات. التأثيرات الوراثية الغير تراكمية (Non- additive) كانت أكثر أهمية للصفات المدروسة. أظهرت السلالات L-7 و -L 1 أفضل قدرة عامة على التوافق للغلة الحبية ووزن الـ 100 حبة في محطة بحوث الجزيرة أما L-13 و11 -L في محطة بحوث معتوق. كانت السلالات L-9، L-12 وL-11 ذات قدرة جيدة عامة على التوافق للبكور. أعطى الهجين L-14×L7 أفضل قوة هجين (79.2 %) للغلة الحبية في محطة بحوث الجزيرة وبينما سجل الهجين L-14×L-3 أعلى قوة هجين (218.1 %) في محطة بحوث معتوق. أبدت الهجن -L 14×L-7، L-14×L-3، L-1×L-9، L-14×L-9 و L-11×L-3 أفضل قدرة خاصة على التوافق مترافقة مع أفضل قوة هجين لذلك ينبغي التوصية بتقييمها في مواقع متعددة لتأكد من ثبات أداءها للغلة الحبية.